DIS AT LOW X, SATURATION SCALE, GLUON STRUCTURE FUNCTION AND VECTOR-MESON PRODUCTION [a]

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Deep inelastic scattering at low x can be described by essentially only two fitted parameters. The interpretation of J/ψ photoproduction in terms of the gluon structure function is elaborated upon.

I will concentrate on the intimate connection between the x-dependence and the Q^2 dependence of the structure function $F_2(x, Q^2)$, and subsequently I will turn to vector-meson production, to J/ψ production in particular.

In deep inelastic scattering (DIS) at low $x \simeq Q^2/W^2 \ll 0.1$, the photon fluctuates into a $q\bar{q}$ color-dipole state that in the virtual forward-Compton-scattering amplitude interacts [1] via the generic structure of two-gluon exchange with the proton. The QCD gauge-theory structure implies diagonal and off-diagonal transitions [2,3] in the masses of the color-dipole vector states, and accordingly it implies a dependence on the transverse three-momentum of the gluon, $\vec{l}_\perp$, that couples to the color dipole. The effective value of $\vec{l}_\perp$ introduces a novel scale, the saturation scale, relevant in low-x DIS. In our approach, the saturation scale, $\Lambda^2_{sat}(W^2)$, depends on the energy, W, and [4]

$$\Lambda^2_{sat}(W^2) = \frac{1}{6}\langle \vec{l}^{\,2}_\perp \rangle \cong \frac{1}{6}\text{const}\left(\frac{W^2}{1GeV^2}\right)^{C_2}. \tag{1}$$

A fit to the total photoabsorption cross section by the power law (1) in the HERA energy range gave [3]

$$2GeV^2 \lesssim \Lambda^2_{sat}(W^2) \lesssim 7GeV^2, \tag{2}$$

[a] Presented at 41st Rencontres de Moriond, March 2006

where

$$\begin{aligned} const &= 0.340 \pm 0.063 GeV^2, \\ C_2 &\equiv C_2^{exp} = 0.27 \pm 0.01. \end{aligned} \tag{3}$$

In addition to $\Lambda^2_{sat}(W^2)$, the total (virtual) photoabsorption cross section depends on the cross section $\sigma^{(\infty)}$ of hadronic size,

$$\sigma^{(\infty)} = 48 GeV^{-2} = 18.7 mb, \tag{4}$$
$$(\text{for } R_{e^+e^-} = 10/3, \text{ four flavours}),$$

and is approximately given by

$$\sigma_{\gamma^* p}(W^2, Q^2) \cong \frac{\alpha}{3\pi} R_{e^+e^-} \sigma^{(\infty)} \cdot \begin{cases} \ln \eta^{-1}, & (\eta \ll 1), \\ \frac{1}{2}\eta^{-1}, & (\eta \gtrsim 1), \end{cases} \tag{5}$$

with the scaling variable [5,3]

$$\eta(W^2, Q^2) = \frac{Q^2 + m_0^2}{\Lambda^2_{sat}(W^2)} \tag{6}$$

and $m_0^2 \simeq 0.15 GeV^2$. Apart from this threshold mass, the cross section (5), or equivalently $F_2(W^2, Q^2)$, contains three adjusted parameters, the two parameters (3) determining the saturation scale and the cross section (4).

Application of DGLAP evolution in the region of $Q^2 \gg \Lambda^2_{sat}(W^2)$, where appropriate, actually reduces the number of three to only two adjusted parameters, since evolution allows one to determine the exponent C_2 in (1). This will be pointed out next.

The representation (5) of the experimental data contains the assumption that the scattering amplitude for longitudinal, $(q\bar{q})_L^{J=1}$, (vector) states and for transverse ones, $(q\bar{q})_T^{J=1}$, be proportional to each other. In terms of the sea-quark, $x\Sigma(x, Q^2)$, and the gluon distribution, $xg(x, Q^2)$, and the proportionality constant r, this proportionality reads [6]

$$\begin{aligned} x\Sigma(x, Q^2) &= \frac{12}{R_{e^+e^-}} F_2(x, Q^2) = \frac{8}{3\pi}\left(r + \frac{1}{2}\right) \alpha_s(Q^2) xg(x, Q^2)|_{x=Q^2/W^2} \\ &= \frac{1}{3\pi^3}\left(r + \frac{1}{2}\right) \sigma^{(\infty)} \Lambda^2_{sat}(W^2). \end{aligned} \tag{7}$$

The constant r also determines the ratio of the longitudinal to the transverse photoabsorption cross section,

$$\frac{\sigma_{\gamma_L^* p}(W^2, Q^2)}{\sigma_{\gamma_T^* p}(W^2, Q^2)} = \frac{1}{2r}. \tag{8}$$

The (successful) representation [3] of the experimental data was based on $r = 1$. With (5) and (7), the evolution equation (at low x) [7]

$$\frac{\partial F_2(\frac{x}{2}, Q^2)}{\partial \ln Q^2} = \frac{R_{e^+e^-}}{9\pi} \alpha_s(Q^2) xg(x, Q^2) \tag{9}$$

turns into an equation for $\Lambda^2_{sat}(W^2)$. Inserting the power law (1), one finds a constraint on C_2 that is given by [6]

$$(2r + 1) 2^{C_2} C_2 = 1. \tag{10}$$

In Table 1, we show the relation between r and C_2 resulting from (10). The constant r, according to (7), determines the relative magnitude of gluon to sea distribution. The dependence of the structure function $F_2(W^2) = F_2(Q^2/x)$ for $Q^2 \gg \Lambda^2_{sat}(W^2)$ follows from (5).

Table 1: Results for $C_2^{theor.}$ for different values of r according to (10).

r	$C_2^{theor.}$	$\alpha_s \cdot$ glue	$\sigma_{\gamma^*_L}/\sigma_{\gamma^*_T}$	$F_2\left(\frac{Q^2}{x}\right)$
$\to\infty$	0	$\ll$ sea	0	$(Q^2/x)^0 = const.$
1	0.276	$\approx$ sea	$\sim\frac{1}{2}$	$(Q^2/x)^{0.276}$
0	0.65	$>$ sea	∞	$(Q^2/x)^{0.65}$

We summarize:

i) The theoretical value of C_2 in Table 1 from (9) and (10) for $r = 1$ coincides with the experimental one (3) obtained for $r = 1$,

$$C_2^{theor.} \simeq C_2^{exp.},$$

and thus the underlying ansatz for the dipole cross section is consistent with the evolution equations from QCD. A (strong) violation of (10) would have ruled out this ansatz, and in particular the underlying assumption of W being the relevant variable to describe diffractive processes at low x.

ii) Essentially two parameters, the normalization of the saturation scale $\Lambda^2_{sat}(W^2)$ in (3) and the cross section of hadronic magnitude (4) are sufficient to determine the low-x proton structure function including the photoproduction limit.

iii) The Q^2 and the x dependence of $F_2(x, Q^2)$ are strongly correlated with each other and correlated with the relative magnitude of the gluon and sea contributions, compare Table 1.

iv) A sufficiently large gluon contribution implies a strong rise of $F_2(x, Q^2)$ with increasing Q^2 for constant x, and an equally strong rise with decreasing x at fixed Q^2 (compare lines 2 and 3 in Table 1). This qualitative feature is experimentally realized, and theoretically it is a natural consequence of W as the relevant variable that describes the scattering cross section of a color dipole on the proton (rather than x).

v) Since the relative magnitude of the gluon and the sea is correlated with $\sigma_{\gamma^*_L p}/\sigma_{\gamma^*_T p}$, direct measurements of this ratio are urgently needed. This allows one to investigate the limits of validity of the underlying assumed proportionality of sea and gluon distributions.

Turning to J/ψ production, in figs. 1 and 2, I show our result[8,4] of an absolute prediction based on the description of the inclusive DIS data I told you about. For details, I have to refer to the original publications.

I wish to mention one important point, however, related to the interpretation of J/ψ photoproduction ($Q^2 = 0$) in terms of the gluon structure function. From (7), valid for sufficiently large $Q^2 \gg \Lambda^2_{sat}(W^2)$, we have

$$\alpha_s(Q^2) x g(x, Q^2)|_{x=Q^2/W^2} = \frac{1}{8\pi^2}\sigma^{(\infty)}\Lambda^2_{sat}(W^2 = Q^2/x). \tag{11}$$

According to (11), a determination of the energy dependence of $\Lambda^2_{sat}(W^2)$ at any Q^2, e.g. at $Q^2 = 0$ in J/ψ photoproduction, yields the dependence of the gluon structure function on the left-hand side as a function of x at $Q^2 \gg \Lambda^2_{sat}(W^2)$, where relation (11) becomes valid. Clearly, the measurement of J/ψ photoproduction does *not* provide a measurement of the structure function for $Q^2 \lesssim m_c^2, \Lambda^2_{sat}(W^2)$, where (11) breaks down.

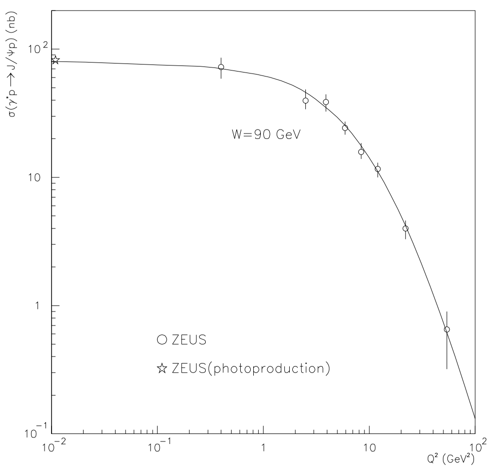

Figure 1: The Q^2 dependence of the cross section for J/ψ production.

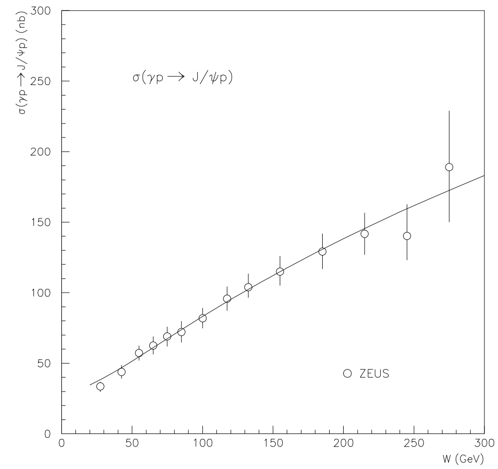

Figure 2: The W-dependence of J/ψ photoproduction

More generally, independent of *our* representation of the data on DIS, *any* unique prediction of J/ψ photoproduction necessarily requires the left-hand side of (11) to only depend on W^2. Otherwise no unique prediction of J/ψ photoproduction will emerge. This should be kept in mind, when predicting the energy dependence of vector meson photoabsorption, i.e. for *any* specific fit of the gluon structure function the left-hand side in (11) should be examined on whether it only depends on W^2 in good approximation at large Q^2.

Acknowledgements

Thanks to Masaaki Kuroda for a fruitful collaboration.
This work was supported by Deutsche Forschungsgemeinschaft under grant SCHI 189/6-2.

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